

Polarization and spin correlation parameters in proton knockout reactions from $s_{1/2}$ -orbits at 1 GeV

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The polarization of the secondary protons ($P_{1,2}$) in the (p,2p) reaction with the S - shell protons of nuclei ^4He , ^6Li , ^{12}C , ^{28}Si , ^{40}Ca was measured at 1 GeV unpolarized proton beam. The spin correlation parameters $C_{i,j}$ for the ^4He and ^{12}C targets also were for the first time obtained. The polarization measurements were performed by means of a two - arm magnetic spectrometer, each arm of which was equipped with multiwire - proportional chamber polarimeter.

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Abstract

The polarization of the secondary protons ($P_{1,2}$) in the (p,2p) reaction with the S - shell protons of nuclei ${}^4\text{He}$, ${}^6\text{Li}$, ${}^{12}\text{C}$, ${}^{28}\text{Si}$, ${}^{40}\text{Ca}$ was measured at 1 GeV unpolarized proton beam. The spin correlation parameters $C_{i,j}$ for the ${}^4\text{He}$ and ${}^{12}\text{C}$ targets also were for the first time obtained. The polarization measurements were performed by means of a two - arm magnetic spectrometer, each arm of which was equipped with multiwire - proportional chamber polarimeter. This experimental work was aimed to study a modification of the proton - proton scattering matrix in the nuclear medium.

1 Introduction

In recent years the question of medium modifications of nucleons and mesons masses and sizes, and of meson - nucleon coupling constants, and, as consequence, of a nucleon - nucleon scattering matrix, has received a great deal of attention [1-6]. These modifications have been motivated from a variety of theoretical points of view, which include renormalization effects due to strong relativistic nuclear fields, deconfinement of quarks, and partial chiral symmetry restoration.

The present work is a part of the wide experimental program in the frame of which medium - induced modifications of nucleon - nucleon scattering amplitudes are studied at PNPI synchrocyclotron with 1 GeV of proton beam energy [7-13]. A (p,2p) reaction with nuclei is considered as the proton - proton scattering in nuclear matter. In the exclusive (p,2p) experiments the two - arm magnetic spectrometer (MAP and NES spectrometers) is used, the shell structure of the nuclei being clearly distinguished. To measure polarization characteristics of the reaction, each arm of the spectrometer is equipped with multiwire - proportional chamber polarimeter.

In joint PNPI - RCNP experiments in 2000 - 2002 years, the polarization of both secondary protons $P_{1,2}$ in the (p,2p) reactions with the 1S - shell protons of nuclei ${}^6\text{Li}$, ${}^{12}\text{C}$ and with the 2S - shell protons of the ${}^{40}\text{Ca}$ nucleus was measured at the nuclear proton momenta before the (p,2p) interaction close to zero [10]. The polarization observed in the experiment (as well as the analyzing power A_y in the RCNP (p,2p) experiment at the 392 MeV polarized proton beam [14,15]) drastically differs from that calculated in the framework of non - relativistic Plane Wave Impulse Approximation (PWIA) and of spin - dependent Distorted Wave Impulse Approximation (DWIA)[16], based on free space proton - proton interaction. This difference was found to be negative and increases monotonously with the effective mean nuclear density $\bar{\rho}$ [14], which is determined by an absorption of initial and secondary protons in nucleus matter. Note also that the observed small difference between the non - relativistic PWIA and DWIA calculations pointed out on a small contribution from the trivial depolarization of secondary protons due to the final state interaction. All these facts strongly indicated a modification

of proton - proton scattering amplitudes due to a modification of main properties of hadrons in nuclear medium. Relativistic calculations have been done to analyze and explain the experimental data [10,12].

The result of the (p,2p) experiment with the ^4He target, performed in 2004 year [11], broke the mentioned above monotonous dependence of a difference between experimental obtained polarization and that calculated in the frame of the PWIA on the effective mean nuclear density $\bar{\rho}$. This difference for the ^4He nucleus proved to be close to that for the ^6Li nucleus in spite of that the ^4He nucleus, according to studies of the elastic nucleon - nucleus scattering, has the largest mean nuclear density. On the other hand mentioned above deviation from the PWIA keeps to be a monotonous function of the S - shell proton binding energy E_s for all the investigated nuclei. It is possible that in light nuclei, where nuclear matter is strongly heterogeneous, the value of $\bar{\rho}$ does not reflect good enough the scale of nuclear medium influence on hadron properties and nucleon - nucleon interaction. The results observed in the (p,2p) experiment with the light nuclei at least show that the value of E_s may also be a measure of the influence of nuclear medium on the pp - interaction.

At present work polarization of the secondary protons $P_{1,2}$ in the (p,2p) reaction with the 1S - shell protons of the ^{28}Si nucleus was measured in the kinematics close to that of the elastic proton - proton scattering (momenta of nuclear protons before interaction were close to zero). The goal of the experiment was to define the relative deviation of experimental polarization from that calculated in the PWIA is determined by the the 1S - proton binding energy E_s or by the the effective mean nuclear density $\bar{\rho}$. The mean value of the E_s for the ^{28}Si nucleus (50 MeV) is essentially larger then that for the ^{12}C nucleus (35 MeV). In the same time the values of the $\bar{\rho}$ seen in the kinematics of the (p,2p) reactions for these nuclei are close to each other due to a saturation of the nuclear matter.

This experimental program was extended to measure the spin correlation parameters $C_{i,j}$ in the (p,2p) reaction with the 1S - shell protons of the ^4He and ^{12}C nuclei. The left index i ($i = n, s'$) and the right index j ($j = n, s''$) are correspond to the forward scattered proton analyzed by the MAP polarimeter and the recoil proton analyzed by the NES polarimeter, respectively. Here \mathbf{n} is the unit vector perpendicular to the scattering plane of the (p,2p) reaction. Unit vectors \mathbf{s}' and \mathbf{s}'' , which lie in the scattering plane, are concerned to the internal coordinate systems of the MAP and NES polarimeters.

The main interest was related to measuring the spin correlation parameter C_{nn} since it's value is the same in the center - of - mass and laboratory systems, and dos't distort by magnetic fields of the two - arm spectrometer due to the proton anomalous magnetic moment [17]. Since the polarization P and the spin correlation parameter C_{nn} depend differently on the scattering matrix element [6], measurement of both these polarization observables in a (p,2p) experiment with nuclei can give more comprehensive information about modification hadron properties in nuclear medium.

2 Experimental method

The general layout of the experimental setup used to investigate (p,2p) reaction with nuclei is presented in Fig. 1.

The experiment is performed at the non - symmetric scattering angles of the final state protons in the coplanar quasi - free scattering geometry with a complete reconstruction of the reaction kinematics. The measured secondary proton momenta K_1 , K_2 and scattering angles Θ_1 , Θ_2 are used together with the proton beam energy T_0 to calculate nuclear proton separation energy ΔE and the residual nucleus momentum \mathbf{K}_r for each (p,2p) event. In impulse approximation, the K_r is equal to the momentum (K) of nuclear proton before the interaction ($\mathbf{K}_r = -\mathbf{K}$).

External proton beam of the PNPI synchrocyclotron was focused onto the target TS of two - arm spectrometer (the magnetic spectrometers MAP and NES). The beam intensity was monitored by the scintillation telescope M1, M2, M3 and was about of $5 \cdot 10^{10}$ protons/(s·cm²).

The solid nuclear targets TS made from CH₂ (for the setup calibration), ⁶Li, ¹²C, ²⁸Si, ⁴⁰Ca (Table 1) and the universal cryogenic target with the liquid helium ⁴He (or with the liquid hydrogen for calibration) were used in the experiment [11,18]. Cylindrical aluminium appendix of the cryogenic target had the following dimensions: diameter - 65 mm, height - 70 mm, wall thickness - 0.1 mm. The diameter of the beam spot on the target was less than 15 mm.

The two - arm spectrometer was used for registration of the secondary protons from the (p,2p) reaction in coincidence and for measurement of their momenta and outgoing angles. The polarization of these protons P_1 and P_2 , and the spin correlation parameters $C_{i,j}$ were measured by the polarimeters located in the region of focal planes of spectrometers MAP and NES. The polarimeter of spectrometer MAP (NES) consisted of proportional chambers PC1÷PC4, PC1', PC4' (PC5÷PC8, PC5', PC8') and carbon analyzer A1 (A2).

The main parameters of the two - arm magnetic spectrometer and polarimeters are listed in Table 2 and Table 3, respectively. The ΔE resolution of the spectrometer estimated on the elastic proton - proton scattering with the 22-mm-thick cylindrical CH₂ target (see Table 1) was found to be about of 5 MeV (FWHM).

The track information from proportional chambers of both polarimeters was used in the offline analysis to find the azimuthal ϕ_1 , ϕ_2 and polar θ_1 , θ_2 angles of proton scattering from the analyzers A1, A2 for each (p,2p) event. In the case of absence of the accidental coincidence background (the case of the elastic proton - proton scattering) the polarization parameters could be found as [19]

$$P_{1,2} = \frac{2 \langle \cos \phi_{1,2} \rangle}{\langle A(\theta_{1,2}, K_{1,2}) \rangle}, \quad (1)$$

$$C_{nn} = \frac{4 \langle \cos \phi_1 \cos \phi_2 \rangle}{\langle A(\theta_1, K_1) \rangle \langle A(\theta_2, K_2) \rangle}, \quad (2)$$

$$C_{s,s,,} = \frac{4 \langle \sin \phi_1 \sin \phi_2 \rangle}{\langle A(\theta_1, K_1) \rangle \langle A(\theta_2, K_2) \rangle}, \quad (3)$$

$$C_{ns,,} = \frac{4 \langle \cos \phi_1 \sin \phi_2 \rangle}{\langle A(\theta_1, K_1) \rangle \langle A(\theta_2, K_2) \rangle}, \quad (4)$$

$$C_{s,n} = \frac{4 \langle \sin \phi_1 \cos \phi_2 \rangle}{\langle A(\theta_1, K_1) \rangle \langle A(\theta_2, K_2) \rangle}, \quad (5)$$

where averaging was made over a set of events within the working angular range of $\theta_{1,2}$ (see Table 3) for the MAP and NES polarimeters. $A(\theta_1, K_1)$ and $A(\theta_2, K_2)$, which were averaged over the same set of events, are the carbon analyzing power parameterized according to [20] and [21] for the MAP and NES polarimeter, respectively.

At present work the polarization parameters were estimated by folding the theoretical functional shape of the azimuthal angular distribution into experimental one [13], using the CERNLIB MINUIT package [22] and likelihood χ^2 estimator [23]. This method permits to realize the control over χ^2 in the case the experimentally measured azimuthal distribution is distorted due to the instrumental problems.

The Time-of-Flight (TOF), the time difference between the signals from the scintillation counters S2 and S4 was measured. This measurement served to control the accidental coincidence background. The events from four neighboring proton beam bunches were recorded. Three of them contained the background events only and were used in the offline analysis to estimate the background polarization parameters and the background contribution at the main bunch containing the correlated (p,2p) events.

The recoil spectrometer NES was installed at a fixed angle $\Theta_2 = 53.22^\circ$. At a given value of the S - shell mean binding energy of nucleus under investigation, the angular and momentum settings of the MAP spectrometer and the momentum setting of the NES spectrometer were chosen to get a kinematics of (p,2p) reaction close to that of the free elastic proton - proton scattering. In this (p,2p) kinematics, momentum \mathbf{K} of the nuclear proton before the interaction is close to zero. At this condition the counting rate of the S - shell proton knockout reaction should be maximal. In Fig. 2 the proton separation energy spectrum for the (p,2p) reaction on the ^{28}Si nucleus, obtained at present work, is presented. As seen from the figure, even at the preferable condition for the S - shell proton knockout process, the contribution from the scattering off the external shell protons is dominant.

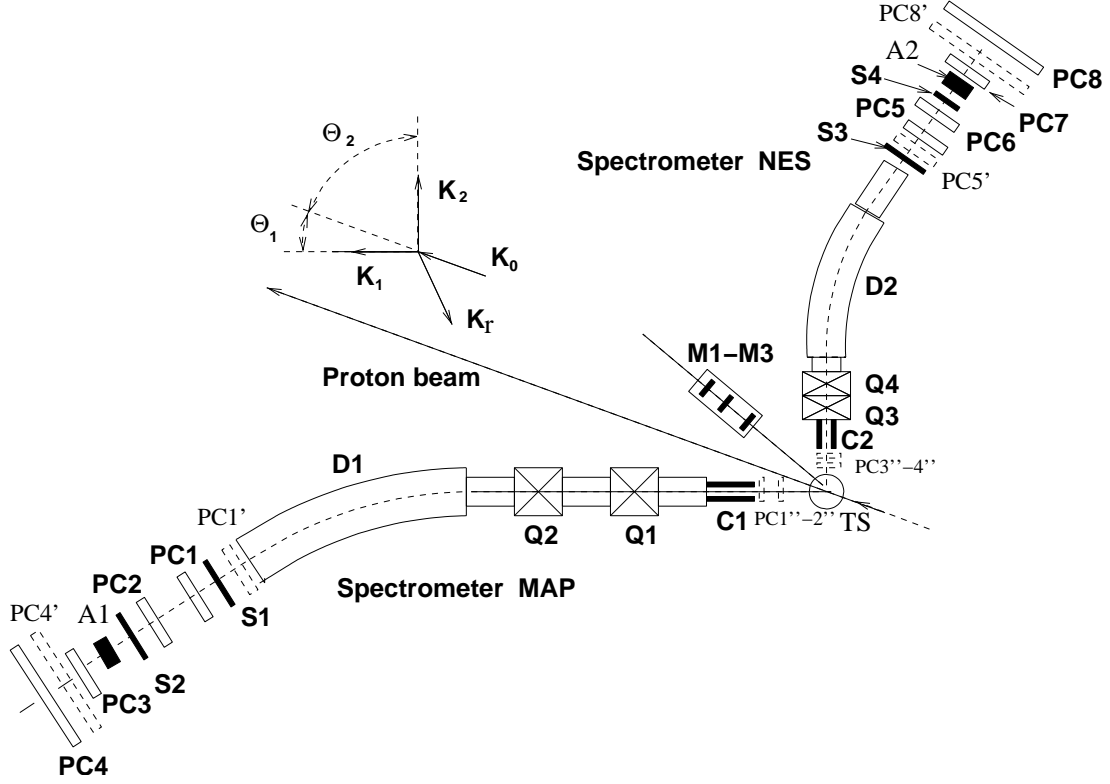


Figure 1: The experimental setup. TS is the target of two - arm spectrometer; $Q1 \div Q4$ are the magnetic quadrupoles; D1, D2 are the dipole magnets; C1, C2 are the collimators; $S1 \div S4$ and $M1 \div M3$ are the scintillation counters; $PC1 \div PC4$, $PC1'$, $PC4'$ ($PC5 \div PC8$, $PC5'$, $PC8'$) and A1 (A2) are the proportional chambers and carbon analyzer of the high - momentum (low - momentum) polarimeter, respectively; $PC1'' \div PC4''$ are the proportional chambers. Shown above is the kinematics for the (p,2p) reaction.

Measurements of the spin correlation parameters and even of the polarization in the (p,2p) reaction with heavy nuclei became possible due the fast proportional chamber readout system (CROS-3), developed and produced at PNPI [13]. This electronics allowed to collect the correlation events without distortion at a high rate of the accidental coincidence background.

TABLE 1: Solid target parameters

Target	Dimensions (mm)	Isotope concentration (%)
CH ₂	diameter x high 22x70 thick x wide x high	
⁶ Li	4.5x12x25	99.0
¹² C	4.0x18x70	98.9
²⁸ Si	6.0x25x70	99.9
⁴⁰ Ca	4.0x10x13	97.0

TABLE 2: Parameters of the magnetic spectrometers

Spectrometer	NES	MAP
Maximum particle momentum (K/Z) ^{max} , GeV/c	1.0	1.7
Axial trajectory radius ρ , m	3.27	5.5
Deflection angle β , deg.	37.2	24.0
Dispersion in focal plane D_f , mm/%	24	22
Solid angle acceptance Ω , sr	$3.1 \cdot 10^{-3}$	$4.0 \cdot 10^{-4}$
Momentum acceptance $\Delta K/K$, %	8.0	8.0
Energy resolution (FWHM), MeV	~ 2.0	~ 1.5

TABLE 3: Polarimeter parameters

Polarimeter	NES	MAP
Carbon block thickness, mm	79	199
Polar angular range, deg.	$5 \div 18$	$3 \div 16$
Average analyzing power	≥ 0.46	≥ 0.23

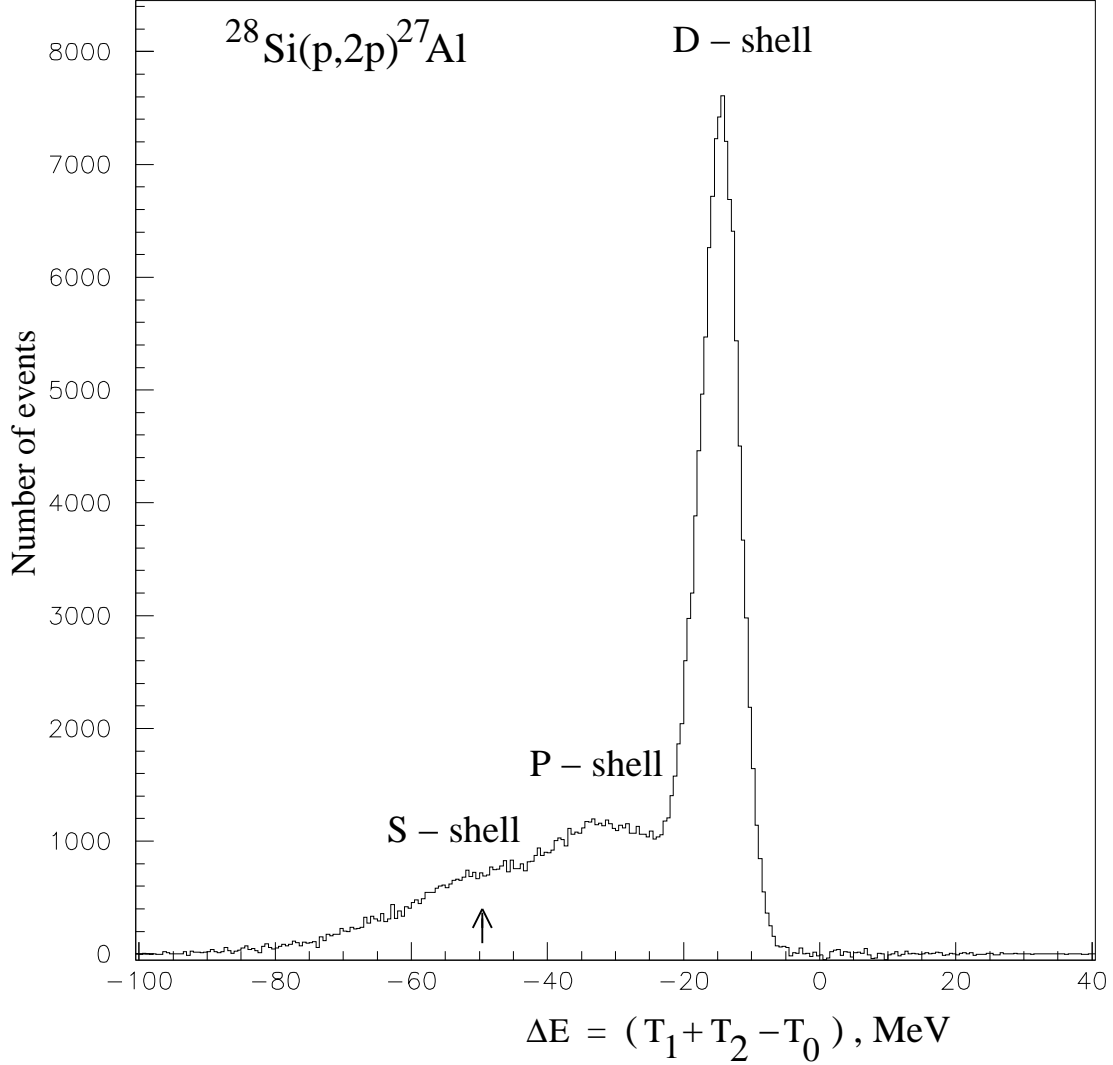


Figure 2: Proton separation energy spectrum for the reaction $^{28}\text{Si}(p,2p)^{27}\text{Al}$.

3 Experimental results and discussion

The measured polarization in the (p,2p) reactions with the S - shell protons of nuclei ^4He , ^6Li , ^{12}C , ^{28}Si , ^{40}Ca is given in Table 4 (see Appendix). In Fig. 3, the averaged values of the data with those obtained earlier in [10] are plotted versus of the S-shell proton binding energy E_s and the effective mean nuclear density $\bar{\rho}$, normalized on the saturation nuclear density $\rho_0 \approx 0.18 \text{ fm}^{-3}$ (see also Table 4). The points (\circ) and (\bullet) in the figure correspond to the polarization P_1 and P_2 of the forward scattered protons at angle $\Theta_1 = 21^\circ \div 25^\circ$ (with the kinetic energy $T_1 = 745 \div 735 \text{ MeV}$) and the recoil protons scattered at the angle $\Theta_2 \approx 53.2^\circ$ (with the energy $T_2 = 205 \div 255 \text{ MeV}$). The points at the $E_s = 0$ are the polarizations P_1 and P_2 in the elastic proton - proton scattering at the angles $\Theta_1 = 26.0^\circ$

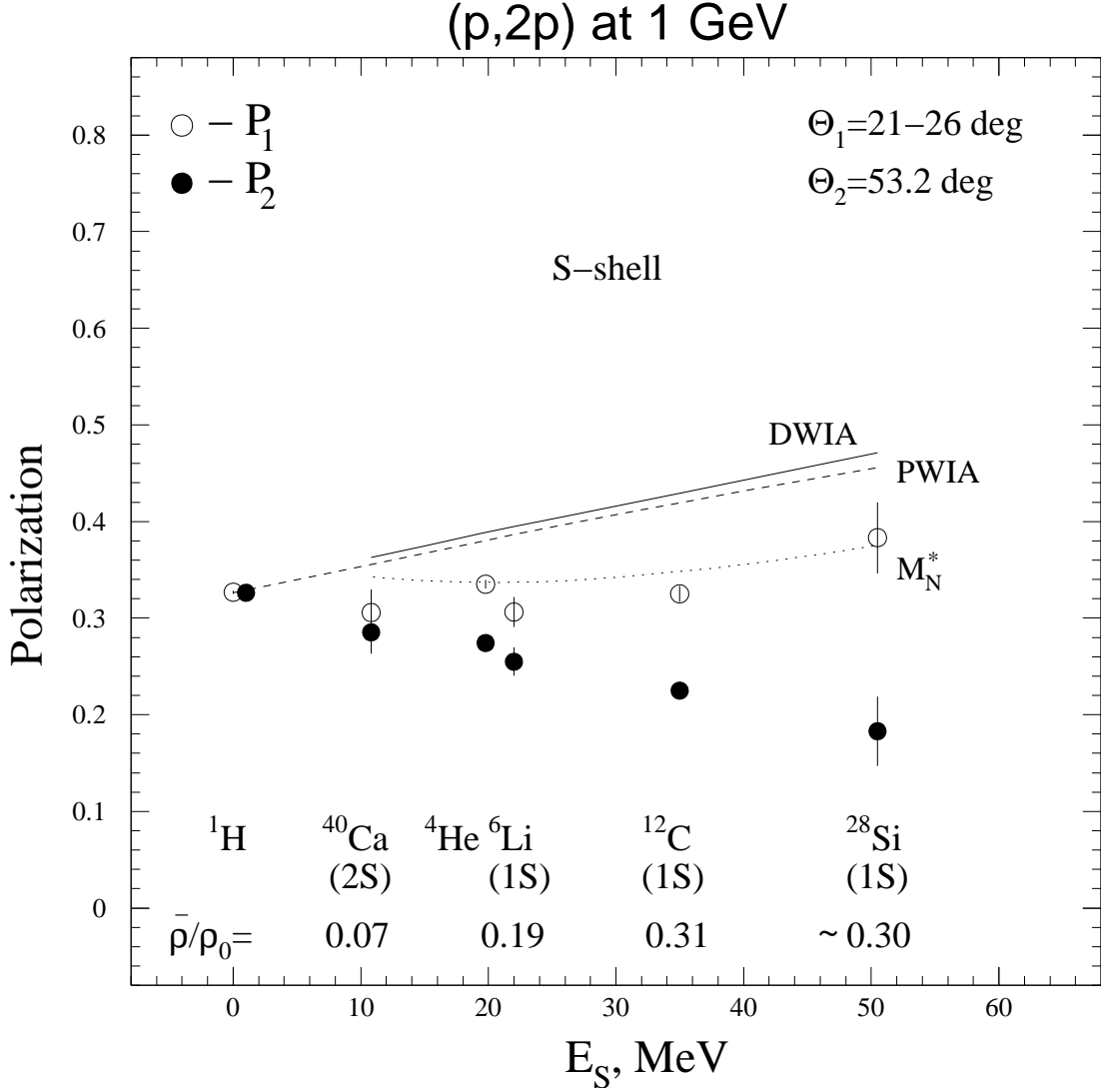


Figure 3: Polarizations P_1 and P_2 of the protons scattered at the angles Θ_1 (\circ) and $\Theta_2 = 53.22^\circ$ (\bullet) in the (p,2p) reaction with the S - shell protons of nuclei at 1 GeV as a function of the mean binding energy E_s and the effective mean nuclear density, $\bar{\rho}$ [14], in units of the saturation density ($\rho_0 = 0.18 \text{ fm}^{-3}$). The points at $E_s=0$ correspond to the elastic proton - proton scattering ($\Theta_1 = 26.0^\circ$). The dashed curve and the solid curve are the results of calculation in the PWIA and the DWIA, respectively, with the NN interaction in free space [16]. The dotted curve is the DWIA result, in which the relativistic effect is taken into account in a Schrödinger equivalent form [5].

and $\Theta_1 = 53.2^\circ$ ($\Theta_{cm} = 62.25^\circ$). Note that these pp - data were obtained by a renormalization of the polarimeter analyzing power requiring that the measured polarization should match the value ($P_{1,2} = 0.326$) given by the current phase - shift analysis SP07 [25]. The normalization coefficient was about of 1.06 for both polarimeters. This correction of the analyzing power was also done for the polarization data obtained in the (p,2p) experiment with nuclei.

In Fig. 3 the experimental data are compared with the results of non - relativistic PWIA (plane wave impulse approximation) and DWIA (distorted wave impulse approximation) calculations employing an on - shell factorized approximation. The dashed and solid curves, corresponding to PWIA and DWIA, respectively, present the results of the calculations, which were obtained using the computer code THREEDDEE [16]. A global optical potential [26], parametrized in the relativistic framework and converted to the Shrödinger - equivalent form, was used to calculate the distorted waves of incident and outgoing protons in the case of DWIA, and a conventional well - depth method was used to construct bound - state wave function. To calculate free observables in the density independent NN interaction, the THREEDDEE code uses the 1986 Arndt NN phase - shift analysis (SP86) [27]. The results of the calculations presented in Fig. 3 were normalized on a ratio of the PWIA predictions obtained with the current phase - shift analysis SP07 and old one SP86. The value of ratio $P(\text{SP07})/P(\text{SP86})$ was about of 1.025. Note here, that the ^4He polarization data were analyzed only in the framework of the PWIA.

Because the difference between P_1 and P_2 values in the DWIA calculations was found to be small, no more than 0.02, only the P_1 values obtained from DWIA are plotted in Fig. 3. As seen from the figure, the difference between the PWIA and DWIA results is quite small. This result suggests that the distortion, in a conventional non - relativistic framework, does not play an essential role in the polarization for the kinematic conditions employed in the present work. The final energy prescription [24] was used for the PWIA and DWIA calculation. We also found that the difference between the initial and final prescriptions was small in these kinematic region. The strong positive slope of the polarizations predicted by these calculations (see Fig. 3) is caused by the kinematic effects of the binding energy of the struck proton.

The differences between the polarizations P_1 , P_2 calculated in the PWIA and those measured in the (p,2p) reaction with nuclei ^{40}Ca , ^6Li , ^{12}C are monotonically increasing functions of the effective mean density (see Fig. 3) [14]. The relative polarization difference $(P_{\text{exp}} - P_{\text{ia}})/P_{\text{ia}}$ is shown in Fig. 4. This difference for the ^{28}Si nucleus, for the forward proton polarization P_1 at least, confirms also that the depolarization effect is determined by the effective mean nuclear density $\bar{\rho}$. Indeed, the values of the relative differences for ^{12}C and ^{28}Si nuclei (\circ - points) are practically equal to each other, these nuclei having the same value of the $\bar{\rho}$ and strongly different the S - shell mean binding energy E_s . This observation provides further evidence that there exists a nuclear medium effect. As seen from Fig. 3-4,

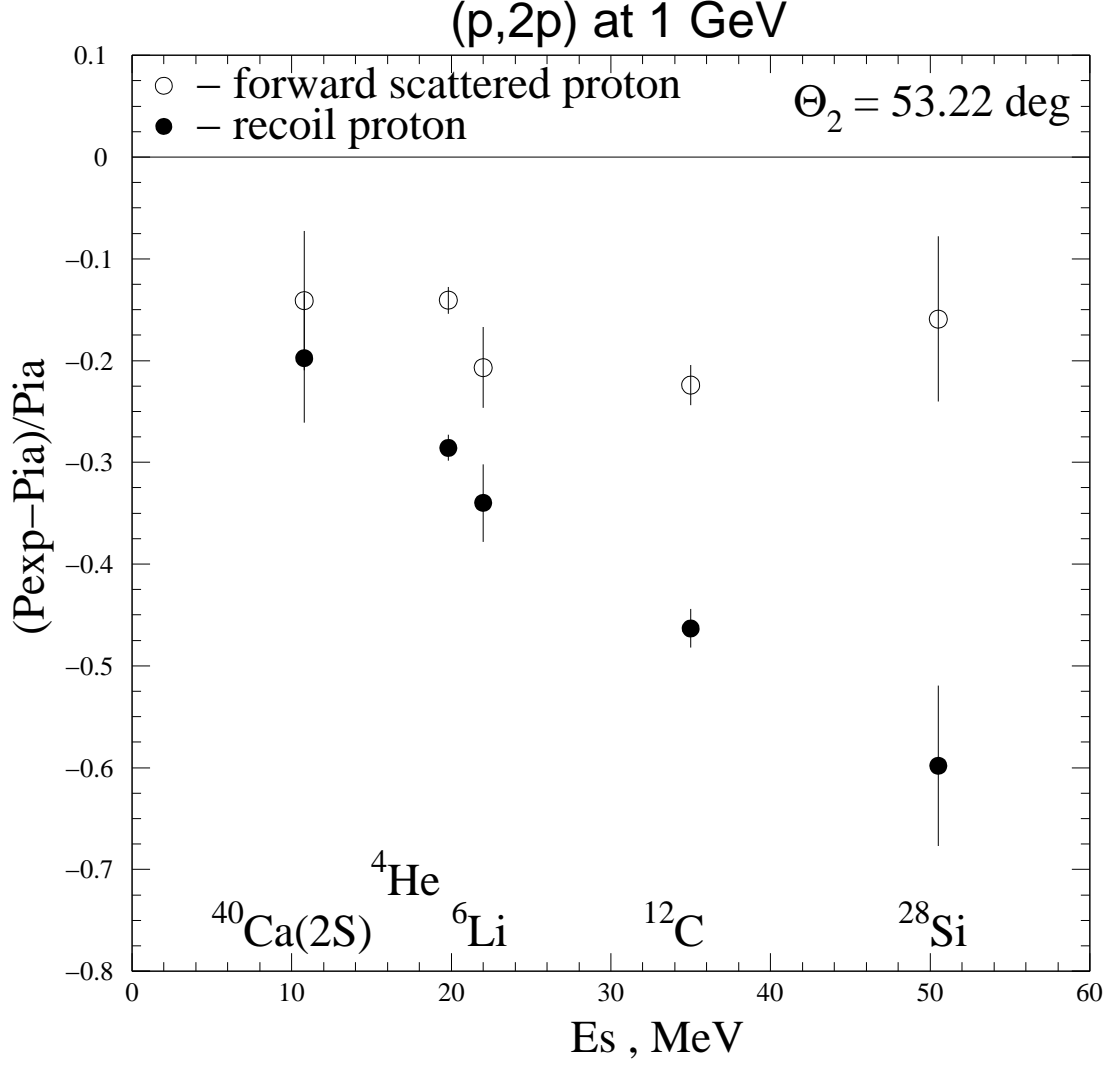


Figure 4: A relative deviation of the polarization observed in the (p,2p) reaction with S - shell protons of nuclei from that calculated in the PWIA. The points (○) and (●) correspond to the forward scattered proton at the angle $\Theta_1 = 21.0^\circ \div 25.08^\circ$ and the recoil proton scattered at the angle $\Theta_2 = 53.22^\circ$, respectively (see Fig. 3).

there is a systematic difference between the P_1 and P_2 values, though they have the same values in the case of elastic pp - scattering. Possible origins of the difference between these values include non - relativistic and relativistic distortions (though the former is excluded if the present DWIA calculations are valid), contributions of multi - step processes, and even nontrivial modification of nucleons in the nuclear field.

In Fig. 3 the experimental data are compared with a theoretical result for the case when a relativistic effect, the distortion of the nucleon spinor, is taken into account. The calculation was carried out in the Shrödinger equivalent form [10] using the THREEDEE code [16]. More specifically, this calculation consists of a non - relativistic DWIA calculation with a nucleon - nucleon t - matrix, that is modified in the nuclear potential following a procedure similar to that proposed by Horowitz and Iqbal [5]. In this approach a modified NN interaction in nuclear medium is assumed due to the effective nucleon mass (smaller than the free mass) which affects the Dirac spinors used in the calculations of the NN scattering matrix. A linear dependence of the effective mass of nucleons on the nuclear density was assumed in the calculations. As seen from the Fig. 3, this relativistic approach gives the results (the dotted curve) close to the experimental values of the forward scattered proton polarization P_1 in the (p,2p) reactions with nuclei at the transferred momenta $q = 3.2 \div 3.7 \text{ fm}^{-1}$ (see Table 4).

Another possible medium effect is the modifications of exchanged meson masses and meson - nucleon coupling constants in the NN interaction. Krein et al. have shown in the relativistic Love - Franey model (RLF) that these modifications cause significant changes in the spin observables which include suppression of A_y [6]. A such type of modification was investigated in [12] using our experimental data on polarization in the (p,2p) reaction with the S - shell protons of the ^{12}C nucleus obtained in a wide range of the momentum transfer q [10]. Note that at present work we essentially improved a statistic accuracy of the polarization measurements in the (p,2p) reaction with the ^{12}C nucleus at the $q = 3.4 \text{ fm}^{-1}$.

In the present work, the spin correlation parameters $C_{i,j}$ in the (p,2p) reactions with the S - shell protons of the ^4He and ^{12}C nuclei were for the first time measured using an unpolarized 1 GeV proton beam.

Since the polarization P and the spin correlation parameter C_{nn} depend differently on the scattering matrix elements [6], measurement of both these polarization observables in a (p,2p) experiment with nuclei can give more comprehensive information about modification of the hadron properties in nuclear medium.

The results of the $C_{i,j}$ measurement in the (p,2p) reaction with nuclei are given in Fig. 5 (Table 5). In Table 5 the measured mean values of the $C_{i,j}$ for the accidental coincidence background, obtained in investigating the (p,2p) reaction with nuclei ^{12}C and ^{28}Si , are also presented. In Fig. 5 the dashed and dotted curves are correspond to the PWIA calculations for the C_{nn} and $C_{s's'}$ spin correlation parameters. In these calculations the current Arndt phase - shift analysis (SP07) was used [25]. The $C_{s's'}$ parameter was found by taking into

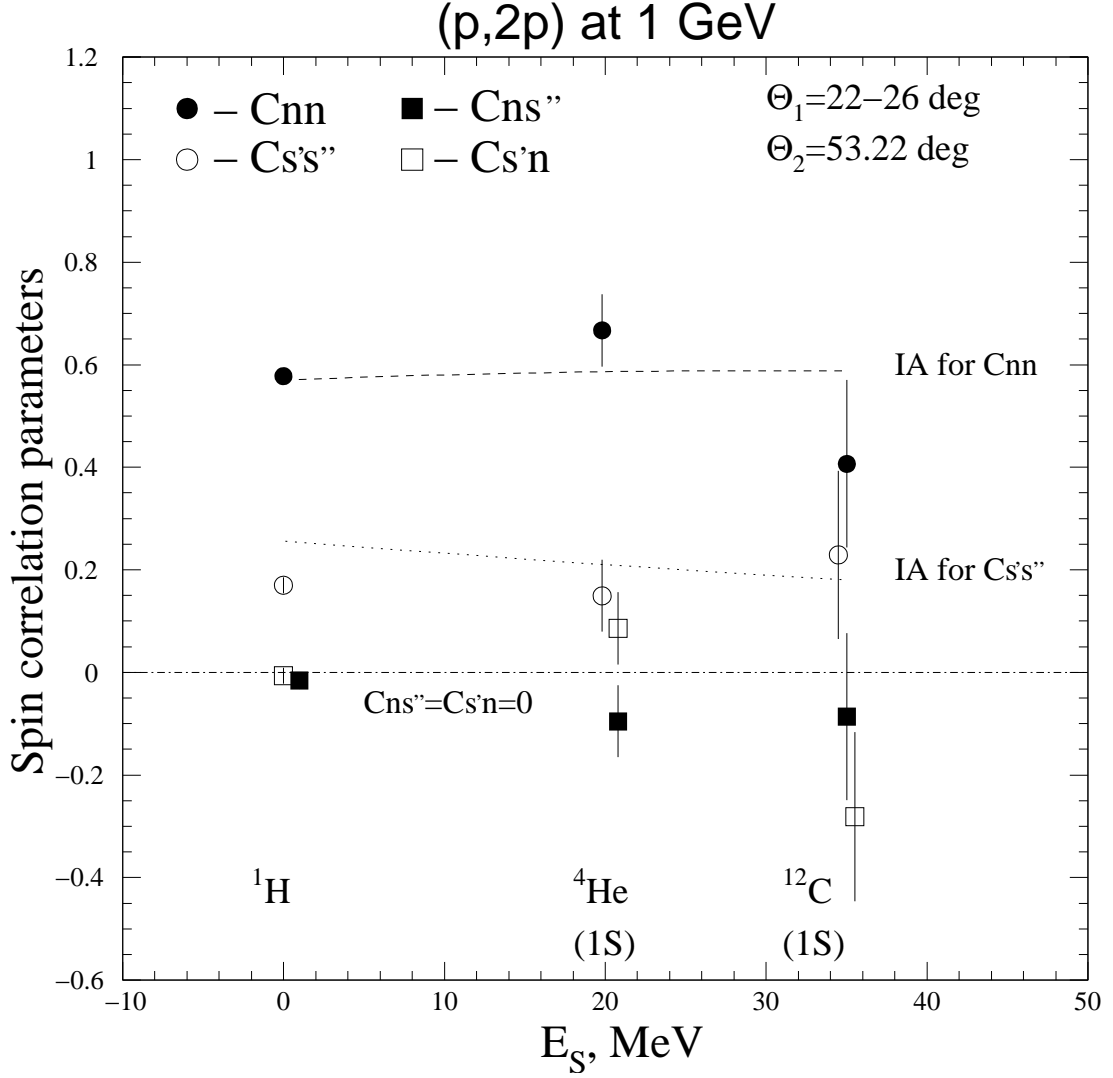


Figure 5: Spin correlation parameters $C_{i,j}$ in the (p,2p) reaction at 1 GeV with the S - shell protons of the ^4He and ^{12}C nuclei at the secondary proton scattering angles $\Theta_2 = 53.2^\circ$, $\Theta_1 = 24.2^\circ$ and $\Theta_2 = 53.2^\circ$, $\Theta_1 = 22.7^\circ$, respectively. The points at $E_s = 0$ correspond to the free elastic proton-proton scattering ($\Theta_1 = 26.0^\circ$, $\Theta_{cm} = 62.25^\circ$), obtained in 2009 year experiment (Table 6). The dashed curve and the dotted curve are the results of the PWIA calculation of the C_{nn} and $C_{s,s'}$, spin correlation parameters.

account its distortion in the magnetic fields of the MAP and NES spectrometers due to an anomalous proton magnetic moment [17]. The points at the mean binding energy value of $E_s = 0$ correspond to the free elastic proton - proton scattering (see Table 6).

As seen from Fig. 5, the differences between the C_{nn} values measured in the (p,2p) experiment with the nuclei and those calculated in the PWIA are within the statistical error bars.

The measured value of the $C_{s,s'}$ parameter in the elastic proton - proton scattering strongly differs from the SP07 prediction. This can be related to a lack of the spin correlation parameter data from the elastic pp - scattering experiments at 1 GeV in the base of the current phase - shift analysis.

Due to the parity conservation in the free elastic proton - proton scattering the spin correlation parameters $C_{ns'}$ and $C_{s'n}$ should be equal to zero. In Fig. 5, this is confirmed by the experimental data at the $E_s=0$. For a (p,2p) reaction with nuclei the parity in the pp - interaction system can be violated since there exists a residual nucleus in the knockout process. However in this case, according to the Pauli principle, a relation $C_{ns'} = -C_{s'n}$ for the pp - interaction system should be performed [28].

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5 Appendix:

TABLE 4: Polarization of secondary protons P_1 and P_2 produced in the (p,2p) reaction at 1 GeV with the S - shell protons of nucleus at lab. angle Θ_1 and Θ_2

Nucleus	Θ_1 deg.	Θ_2 deg.	T_1 MeV	T_2 MeV	q fm^{-1}	P_1	P_2	$\bar{\rho}/\rho_0$
^4He (1S)	24.21	53.22	738	242		0.336 ± 0.005	0.274 ± 0.005	
$\langle ^4\text{He}$ (1S) \rangle	24.21	53.22	738	242	3.6	0.335 ± 0.005	0.274 ± 0.004	
^6Li (1S)	24.0	53.22	738	241		0.309 ± 0.026	0.247 ± 0.023	
$\langle ^6\text{Li}$ (1S) \rangle	24.0	53.25	739	239	3.6	0.306 ± 0.015	0.255 ± 0.015	0.19
^{12}C (1S)	22.71	53.22	746	219		0.329 ± 0.009	0.227 ± 0.008	
$\langle ^{12}\text{C}$ (1S) \rangle	22.71	53.22	746	219	3.4	0.325 ± 0.008	0.225 ± 0.008	0.31
^{28}Si (1S)	21.0	53.22	746	204	3.2	0.383 ± 0.037	0.183 ± 0.036	~ 0.30
^{40}Ca (2S)	25.05	53.22	733	256		0.306 ± 0.037	0.304 ± 0.033	
$\langle ^{40}\text{Ca}$ (2S) \rangle	25.08	53.15	734	255	3.7	0.306 ± 0.024	0.286 ± 0.023	0.07

TABLE 5: Spin correlation parameters C_{ij} in the (p,2p) reaction at 1 GeV with the 1S - shell protons of the ^4He and ^{12}C nuclei at lab. angles Θ_1 and $\Theta_2 = 53.22^\circ$. The line "Background" corresponds to the measured mean values of the C_{ij} for the accidental coincidence background, obtained in investigating the (p,2p) reaction with nuclei ^{12}C and ^{28}Si

Nucleus	Θ_1 deg.	C_{nn}	$C_{s's''}$	$C_{ns''}$	$C_{s'n}$
^4He	24.21	0.667 ± 0.070	0.150 ± 0.070	-0.095 ± 0.070	0.086 ± 0.070
^{12}C	22.71	0.407 ± 0.163	0.229 ± 0.164	-0.086 ± 0.163	-0.281 ± 0.165
Background		-0.003 ± 0.020	0.005 ± 0.020	0.019 ± 0.020	0.004 ± 0.020

TABLE 6: Spin correlation parameters C_{ij} in the elastic proton - proton scattering at 1 GeV at lab. angles $\Theta_1 = 26.0^\circ$ and $\Theta_2 = 53.22^\circ$ ($\Theta_{cm} = 62.25^\circ$), obtained in 2007-2010 years. The current phase - shift analysis predicts the C_{nn} value of 0.57. The statistical errors in the measurements of the polarizations P_1 and P_2 are also given

Year	C_{nn}	$C_{s's''}$	$C_{ns''}$	$C_{s'n}$	δP_1	δP_2
2007	0.587 ± 0.021	0.115 ± 0.021	0.005 ± 0.021	0.080 ± 0.021	0.0015	0.0012
2008	0.584 ± 0.014	0.195 ± 0.014	-0.004 ± 0.014	0.008 ± 0.014	0.0010	0.0009
2009	0.577 ± 0.016	0.170 ± 0.016	-0.016 ± 0.016	-0.006 ± 0.016	0.0015	0.0013
2010	0.455 ± 0.052	0.162 ± 0.052	-0.050 ± 0.052	0.009 ± 0.052	0.0041	0.0036

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